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SEQUENTIAL SAMPLING OF DOUGLAS-FIR TUSSOCK MOTH POPULATIONS

by

Richard R. Mason
Insect Ecologist

ABSTRACT

Sequential plans have been constructed for sampling eggs and larvae of the Douglas-fir tussock moth. The plans are a standardized method for making quick ground surveys of incipient outbreaks. They are designed to be applied independently at selected points in an suspected infestation for distinguishing currently innocuous populations from those having outbreak potential. The sequential schemes are recommended primarily for sampling tussock moth larvae in the early instar.

INTRODUCTION

The Douglas-fir tussock moth, *Hemerocampa pseudotsugata* McDunnough, is an important defoliator of Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco and the true firs, *Abies* spp. Tussock moth outbreaks have a history of developing unexpectedly. Often the sudden appearance of defoliated trees may be the first indication of an infestation. Immediately prior to an outbreak, when defoliation is not yet evident, the incipient infestation is sometimes difficult to detect. However, on careful examination, larvae are often fairly common in the foliage of many trees. On the other hand, conspicuous feeding on a few trees, although it may indicate a local population center, does not

necessarily portend a general outbreak the following year. In these situations, extensive ground surveys are needed that will give a standard quantitative assessment of populations over the whole suspected area.

Sequential sampling is a rapid and systematic way of evaluating populations in incipient outbreaks. Because population levels are classified into general categories, sequential sampling requires much less time than is needed for precise population estimates. The methods described in this paper are especially useful for making rapid surveys around newly discovered spots that may require early control action. The sequential schemes were constructed so that low populations with little chance of increasing to a destructive level in 1 year can be quickly distinguished from higher populations that seem to have outbreak potential.

Field methods for precisely estimating the size of tussock moth populations from a fixed number of tree samples have been developed and are reported in another paper.[1/] In sequential sampling, identical techniques are used for taking foliage samples from the tree; however, the number of trees to be examined to classify a population is variable. The data used in developing the sequential sampling methods in this paper were gathered largely from tussock moth infestations in white fir, *Abies concolor* (Good. and Glend.) Lindl., and may not be representative of infestations in other tree species.

THE SAMPLE UNIT

The basic sample unit is a collection of twigs or branches, called subsamples, taken representatively from a tree. Twigs are used for sampling larvae and whole branches for sampling egg masses. The arrangement of subsamples needed to represent the crown correctly depends on which stage of the insect is being sampled. Recommended procedures for sampling foliage are given on pages 5 and 6 for larvae and page 8 for egg masses.

Population size is the density of insects per 1,000 square inches of branch area. Branch area is the square inches occupied by foliage on a twig or branch, estimated by the foliated length measured along the stem and multiplied by one-half the maximum width of foliage on the twig or branch. For determination of insect density, the number of egg masses

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[1/] Mason, Richard R. Development of sampling methods for the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). 1969. (In preparation for publication by Pacific Northwest Forest & Range Exp. Sta., Forest Serv., U.S. Dep. Agr., Portland, Oregon.)

or larvae on the subsamples is related to total branch area of the sample unit and then corrected to a uniform area of 1,000 square inches as follows:

$$\text{Number of larvae (or egg masses) per 1,000 sq. in.} = \frac{\text{Total larvae (or egg masses) on subsamples}}{\text{Total branch area (sq. in.) of subsamples}} \times 1{,}000$$

CONSTRUCTING THE SEQUENTIAL PLANS

Basic requirements for development of a sequential sampling plan are: (1) knowledge of the frequency destribution of the insect population and (2) the biological significance of different size populations for setting class limits. Previous work shows that tussock moth populations conform to a negative binomial distribution.[2/] Setting class limits depends on the type of information wanted for the population in question.

Classes for the sequential schemes given in this paper were established primarily for separating low, insignificant populations from larger populations which seem to have the numerical potential for rapidly expanding into an outbreak. This two-class scheme allows for the quickest possible classification of a population. Normally, these class limits are below the level at which defoliation is readily discernible from aerial observation; therefore, the calculated plans are essentially a technique for ground detection and appraisal of incipient infestations. Class limits for the plans are:

Light population (outbreak not imminent) = 10 or less first-instar larvae or eggs per 1,000 sq. in. of branch area.

Heavy population (outbreak imminent) = 20 or more first-instar larvae or eggs per 1,000 sq. in. of branch area.

For establishing class limits, eggs instead of egg masses are used because they are more comparable to larvae on a numerical basis. Although egg masses are the units counted in the field, the number of eggs in the masses is the major interest and, therefore, is the value on which the sequential plan is built. Later, a conversion to egg masses is made for field use based on the number of eggs in an average mass.

[2/] See footnote 1.

Formulae for the calculation of decision lines used in constructing the sequential plans have been published by Waters.[3/] The parameter, k, a coefficient reflecting aggregation in the negative binomial distribution, is in the formulae and has a great effect on the slope and spacing of the decision lines used to construct the sequential plan. A small k implies a high degree of aggregation and a large k, low aggregation.

Common k values have been calculated from field data for larvae and eggs.[4/] Larvae have a k value of 2.358 and eggs a value of 0.425. The relatively low k for eggs is due to the high aggregation of eggs in masses, whereas the value for larvae is large because they are more dispersed through the tree foliage. Decision lines for the calculated sequential plans are shown in figures 1 and 2. Lines are plotted for

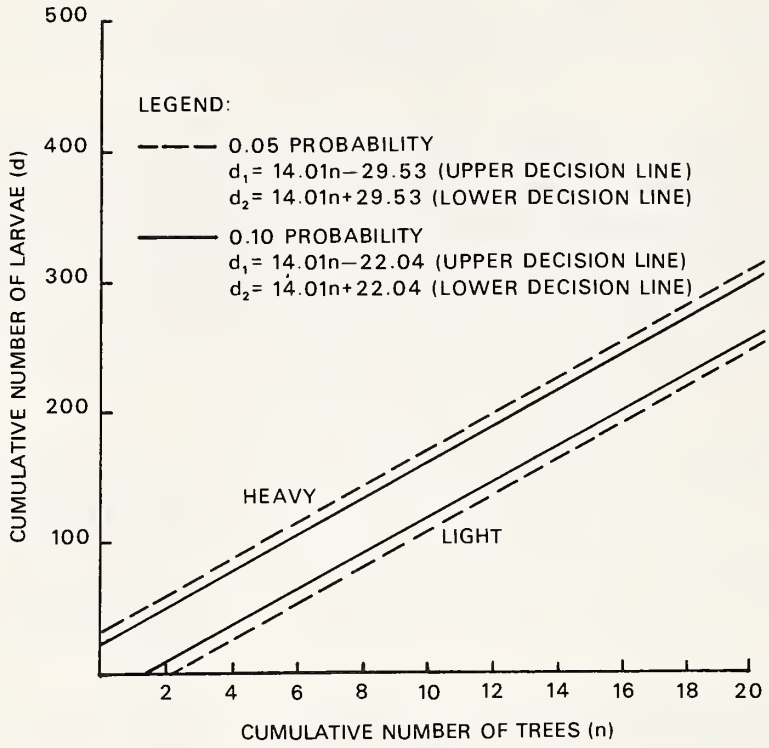


Figure 1.--*Sequential graph for classifying Douglas-fir tussock moth larvae into two population levels.*

[3/] Waters, W. E. Sequential sampling in forest insect surveys. Forest Sci. 1: 68-79. 1955.

[4/] See footnote 1.

two confidence levels for the α and β errors inherent in a sequential sampling plan.[5/] The lines for eggs are much wider apart than they are for larvae, which means that more sampling is needed to reach a decision for eggs than for larvae. Therefore, populations can usually be classified quickest by sampling the larval stage.

PROCEDURES FOR SEQUENTIAL SAMPLING OF LARVAE

Tussock moth larvae in the midcrown of the tree are consistently representative of larval density over the whole crown; therefore, only this portion of the crown needs to be sampled.[6/] The midcrown itself can be sampled representatively by taking three foliated twig samples about 17 inches long in a 1:2 combination, respectively, from the

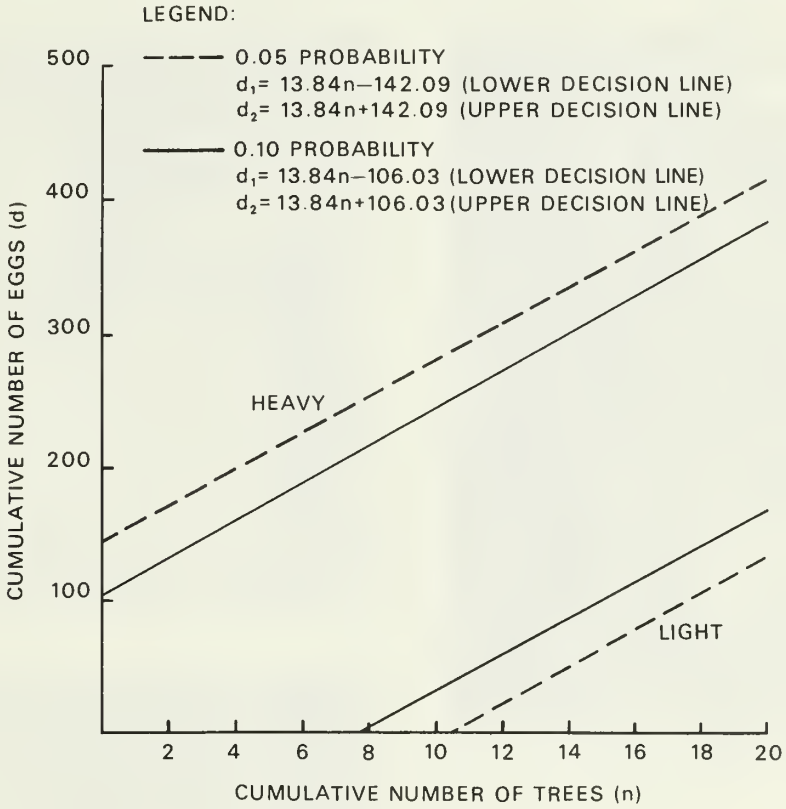


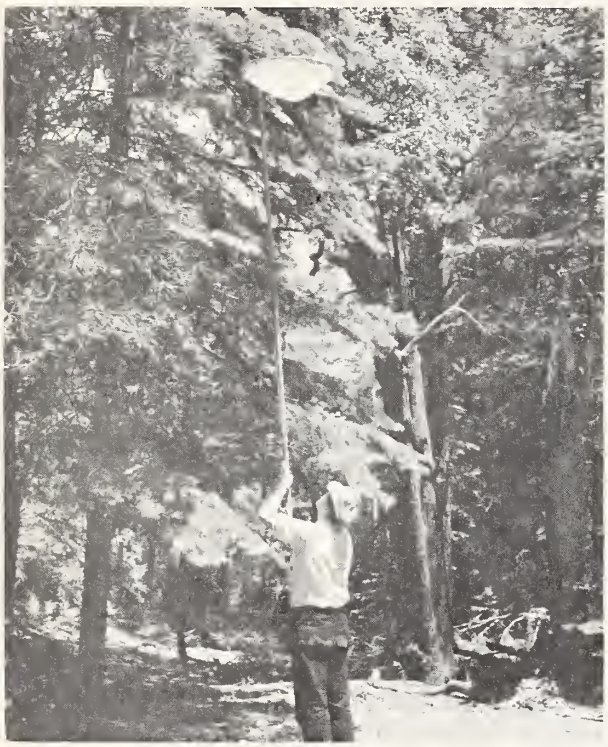
Figure 2.--*Sequential graph for classifying Douglas-fir tussock moth eggs into two population levels.*

5/ See footnote 3.

6/ See footnote 1.

outside and inside portion of the midcrown. The outside crown is defined as the outer 17 inches at the end of the main branch; the inside crown is all foliage on side branches at least 17 inches in from the end of the main branch.

Twig samples can be clipped from the tree with a pole pruner and collected in a cloth basket attached to the end of the pole just below the cutting head. Special care should be taken not to disturb the twig or other foliage on the tree before it is clipped lest agitated larvae drop from the sample before it is secure in the basket. Larvae can be dislodged for counting if the sample is held over a white cloth on the ground and rapped sharply with a stick (fig. 3). After larvae have been counted on all three twigs, their density per 1,000 square inches of branch area can be calculated (see page 3).



A

B

C

Figure 3.--*Field sampling of tussock moth larvae:* A, *pole pruner with attached basket for clipping twig subsamples from tree;* B, *rapping twig to dislodge larvae;* C, *measuring twig to determine branch area.*

In table 1, sequential data are compiled for field use, giving the number of trees and larvae needed to classify a population at different confidence levels. Larval density values are accumulated from sample trees until: (1) the cumulative total is equal to or less than the stipulated total in the "light" column for the number of trees sampled, in which case the population is classified as light;

Table 1.--*Sequential plan for classifying Douglas-fir tussock moth larval populations, by two levels of confidence*[1/]

Number of trees	Cumulative total of number of larvae per 1,000 sq. in.			
	0.1 confidence level		0.05 confidence level	
	Light	Heavy	Light	Heavy
1	--	37	--	44
2	5	51	--	58
3	19	65	12	72
4	33	79	26	86
5	47	93	40	100
6	61	107	54	114
7	75	121	68	128
8	89	135	82	142
9	103	149	96	156
10	117	163	110	170
11	131	177	124	184
12	145	191	138	198
13	160	206	152	212
14	173	219	166	226
15	187	233	180	239
16	201	247	194	253
17	216	261	208	268
18	229	275	222	282
19	243	289	236	296
20	257	303	250	310

[1/] Larvae are counted on three twigs, sampled in a 2:1 combination, respectively, from the inside and outside of the middle crown of each tree. Sampling should continue as long as cumulative total falls between counts listed in "light" and "heavy" columns.

or (2) the cumulative total is equal to or more than the total in the "heavy" column, in which case the population is classified as heavy. As long as the cumulative total falls between the "light" and "heavy" columns, sampling continues.

A special tally sheet (fig. 4) can be prepared which will greatly facilitate the use of the sequential scheme during the actual survey. The sequential plan is written in the squares across the top of the columns and gives the upper and lower limits of cumulative values needed to reach a decision on classification. The upper left corner gives the upper limit for a light population and the lower right corner the lower limit for a heavy population. As trees are sampled, the insect density values are accumulated and recorded in the square across the page opposite the sample point that is being examined and beneath the appropriate tree taken in sequence. When the cumulative total sampled is equal to or less than the specified limit in the upper left corner of the overhead box, sampling is terminated and the point is classified light. If the cumulative total is equal to or more than the limit in the lower right corner of the box, the point is classified heavy.

PROCEDURES FOR SEQUENTIAL SAMPLING EGGS

In low-level populations, egg masses of the tussock moth are found in almost any part of the tree crown. Until further work is done to establish a portion of the crown that may be a reliable indicator of the egg population over the whole tree, the entire crown must be sampled. For a representative sample, four whole branches should be taken in a 1:2:1 combination, respectively, from the upper, middle, and lower crown. These areas of the crown are defined as the foliated branches stemming from the upper, middle, and lower thirds of the tree bole. Egg masses on the four whole branches are counted and their density per 1,000 square inches of branch area is calculated.

Field plans for sequential sampling of eggs are given in table 2. To facilitate the use of the table in the field, the number of eggs in figure 2 was converted to egg masses by dividing by 260, the approximate number of eggs per mass in a low-level population.[7/] If there is reason to believe that the average number of eggs per mass in the area to be evaluated differs significantly from 260, the factors may have to be corrected by presampling egg masses, and a new field table will need to be compiled. However, in relatively low populations, for which this sequential plan has been constructed, a value of 260 eggs per mass is probably appropriate. In high populations, where overcrowding might affect fecundity, the conversion value could be much smaller.

7/ See footnote 1.

Location _____ Date _____

Cumulative Number of Trees

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Point No.	L / H	5 / 51	19 / 65	33 / 79	47 / 93	61 / 107	75 / 121	89 / 135	103 / 149	117 / 163	131 / 177	145 / 191	160 / 206	173 / 219	187 / 233
1															
2															
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Figure 4.--*Sample form sheet for tallying larvae in field at a confidence level of 0.10.*

Egg mass densities are accumulated from consecutive trees until a decision is reached on light or heavy populations in the same manner as described for larvae. It can be seen in the sample plan in table 2 that at the 0.1 confidence level, a minimum of eight trees with no egg masses have to be sampled before a "light" decision can be reached;

Table 2.--*Sequential sampling plan for classifying Douglas-fir tussock moth egg populations, by two levels of confidence*[1/]

Number of trees	Cumulative total of number of egg masses per 1,000 sq. in.			
	0.1 confidence level		0.05 confidence level	
	Light	Heavy	Light	Heavy
1	--	0.46	--	0.60
2	--	.52	--	.65
3	--	.57	--	.71
4	--	.62	--	.76
5	--	.67	--	.81
6	--	.73	--	.87
7	--	.78	--	.92
8	0.02	.83	--	.97
9	.07	.88	--	1.03
10	.12	.94	--	1.08
11	.18	.99	0.04	1.13
12	.23	1.04	.09	1.18
13	.28	1.10	.15	1.24
14	.34	1.15	.20	1.29
15	.39	1.21	.25	1.35
16	.44	1.26	.30	1.40
17	.50	1.31	.36	1.45
18	.55	1.37	.41	1.50
19	.60	1.42	.47	1.56
20	.66	1.47	.52	1.61

[1/] Egg masses, assumed to contain an average of 260 eggs per mass, are counted on four whole branches, sampled in a 1:2:1 combination, respectively, from the upper, middle, and lower crown of each tree. Sampling should continue as long as cumulative total falls between counts listed in "light" and "heavy" columns.

conversely, a mean egg mass density of only 0.46 per 1,000 square inches on the first sample will give a classification of heavy for that point. This occurs because of the large number of eggs in a single mass which greatly increases the probability of a population being over 20 insects per 1,000 square inches.

USING SEQUENTIAL PLANS FOR A SURVEY

To evaluate a population in a potential outbreak, numerous sample points need to be visited over the area from which population information is desired. The spacing of sample points depends entirely on the intensity with which the area needs to be surveyed. The sequential sampling plan is applied independently at each point. A sample point should consist of approximately 1 acre where trees are randomly selected and sampled until the population at the point can be classified as either light or heavy. After a number of sample points have been classified, infestation patterns in the area will probably become apparent and can be delineated on a map.

The light and heavy infestation classes have been based on numbers of eggs or first-instar larvae. Therefore, for effective use of these classes, timing of the larval sample is critical because numbers decline sharply after larvae are hatched. If older larvae are sampled, the classification schemes as designed become less meaningful.

In endemic populations, there will be a much higher probability of sampling young larvae which are dispersed in the foliage than of sampling eggs that are aggregated in masses. This fact is reflected in the sequential plans which stipulate that considerably less sampling is required to classify larval than egg populations. For this reason, extensive surveys for detection in low-level situations will be most efficient if they are timed to sample the easier found early-instar larvae. Surveys at that stage should be reasonably comparable to egg surveys, but they can be performed at the same precision with considerably less work. Moreover, the number of first-instar larvae may actually be a more realistic value for the population than eggs, because parasitized and nonviable eggs would not affect the estimate.